ELECTROWEAK PHYSICS AND SEARCHES FOR NEW PHYSICS AT HERA

U.Schneekloth [a]
Deutsches Elektronen-Synchrotron DESY
Hamburg, Germany

Abstract. Recent results from the H1 and ZEUS experiments are reported on electroweak physics and on searches for new physics. All results are in good agreement with the Standard Model.

1 Introduction

High energy electron- (positron-) proton collisions at the HERA collider, colliding 27.5 GeV electrons (or positrons) on 920 GeV protons, provide a unique opportunity for studying electroweak physics and for searches for physics beyond the Standard Model. Extensive studies have been performed by the H1 and ZEUS collaborations with the final data sets, corresponding to an integrated luminosity of about 0.5 fb^{-1} per experiment. Recently, significant improvements have been achieved by combining the results of both experiments. A summary of electroweak studies and searches for new physics is presented in this paper.

2 Evidence for Electroweak Unification

One of the main goals of the HERA physics program has been the precise measurement of the differential cross sections in neutral (NC) and charged current (CC) deep inelastic scattering (DIS). These measurements have not only been of great importance for the understanding of the quark and gluon content of the proton, but have also provided a basis for electroweak (EW) studies [1].

Figure 1 shows the single differential NC and CC e^+p and e^-p cross sections measured by H1 [2, 3] and ZEUS [4] for $Q^2 > 200\,\mathrm{GeV}^2$ as a function of the momentum transfer Q^2. The NC data show a $1/Q^4$ behavior due to the electromagnetic current, whereas the CC cross section is proportional to $1/(Q^2 + M_W^2)^2$, which gives a much less steeper cross section decrease as a function of Q^2, since the propagator term includes the W mass. At high Q^2, $Q^2 > M_W^2$, both NC and CC are mediated by a unified electroweak current and both cross sections are of comparable size. There is excellent agreement with the SM predictions over 7 (4) orders of magnitude for NC (CC) scattering.

[a] e-mail: uwe.schneekloth@desy.de

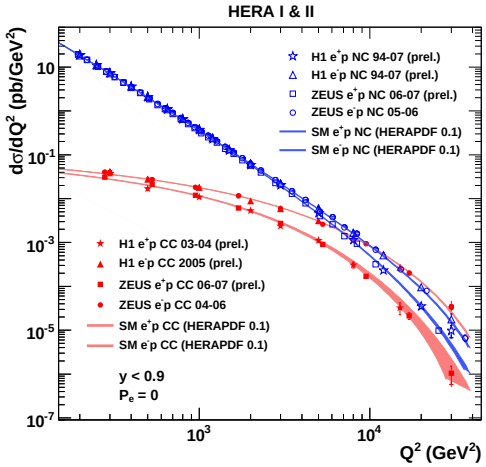

Figure 1: *Differential cross section for NC and CC ep scattering, as measured by H1 and ZEUS, compared to the SM expectations using the HERAPDF parametrization of the proton parton distribution functions.*

3 Neutral Current Cross Sections

The unpolarized NC cross section has been measured over a large range of Q^2 (200 - 30 000 GeV^2) for e^-p and e^+p DIS. At high Q^2, the e^-p cross section is significantly larger than the e^+p cross section. This charge asymmetry can be exploited to measure the interference structure function $xF_3^{\gamma Z}$:

$$xF_3^{\gamma Z} \simeq x\tilde{F}_3 \frac{(Q^2 + M_Z^2)}{\alpha_e \kappa Q^2}, \qquad x\tilde{F}_3 = \frac{Y_+}{2Y_-}(\tilde{\sigma}^{e^-p} - \tilde{\sigma}^{e^+p}).$$

Since $xF_3^{\gamma Z}$ has little dependence on Q^2, the measurements from $1\,500 < Q^2 < 30\,000\,\mathrm{GeV}^2$ were extrapolated to $5\,000\,\mathrm{GeV}^2$ and then averaged to obtain higher statistical significance. Figure 2 shows $xF_3^{\gamma Z}$ measured at $Q^2 = 5\,000\,\mathrm{GeV}^2$ [6]. It is well described by the SM prediction.

A direct measure of EW effects are the charge dependent polarization asymmetries of the NC cross sections, which are now accessible using the HERA II data. The cross section asymmetries $A^{\pm}$, as defined below, can be used to measure to a good approximation the structure function ratio, which is proportional to the product $a_e v_q$, where $a_e(v_q)$ is the axial (vector) coupling of the electron (quark q) to the Z boson, and thus gives a direct measure of parity violation.

$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \simeq \mp \kappa a_e \frac{F_2^{\gamma Z}}{F_2} \propto a_e v_q,$$

where P_R (P_L) is the right (left) handed lepton beam polarization.

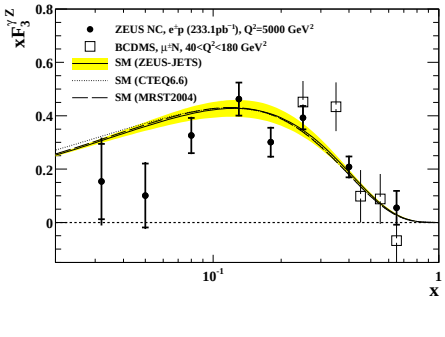

Figure 2: *The structure function $xF_3^{\gamma Z}$ extrapolated to a single Q^2 value of 5 000 GeV^2, plotted as a function of x.*

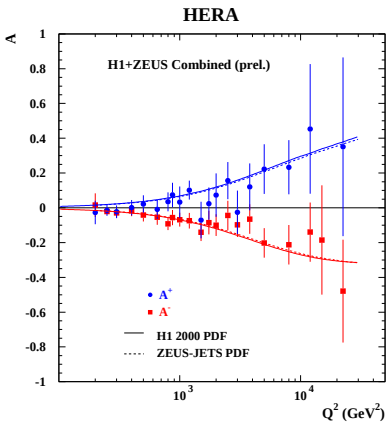

Figure 3: *The polarization asymmetry A plotted as a function Q^2.*

The asymmetries obtained from the combined H1 and ZEUS data are shown in Fig. 3 [7] and are well described by the SM predictions as obtained from the H1 and ZEUS QCD fits. The data demonstrate parity violation at very small distances, down to 10^{-18} m.

4 Polarized Charged Current Cross Sections

The total CC cross sections have been measured by H1 [3] and ZEUS [4] as a function of the lepton beam polarization P_e in the common phase space $Q^2 > 400\,\mathrm{GeV}^2$ and $y < 0.9$. In Fig. 4 the results are compared with SM predictions based on CTEQ6D, MRST 2004 and HERAPDF0.1 fits. The linear dependence of the CC cross sections on P_e is expected as the W boson interacts only with e_L^- and e_R^+. A straight line fit to these cross sections is sensitive to exotic right-handed and left-handed current additions to the SM Lagrangian. Assuming SM couplings and a massless right-handed neutrino, the existence of charged currents involving right-handed fermions mediated by a boson of mass below 208 GeV is excluded at 95% C.L. [5].

5 Combined Electroweak-QCD Fits

The NC cross sections provide information on the quark couplings to the Z^0 boson. For the HERA kinematic regime, the axial (a_q) and vector (v_q) coupling constants are dominant in the unpolarized xF_3^0 and polarized F_2^P structure functions, respectively. These electroweak parameters can be fitted simultaneously with the PDF parameters to perform a model independent extraction.

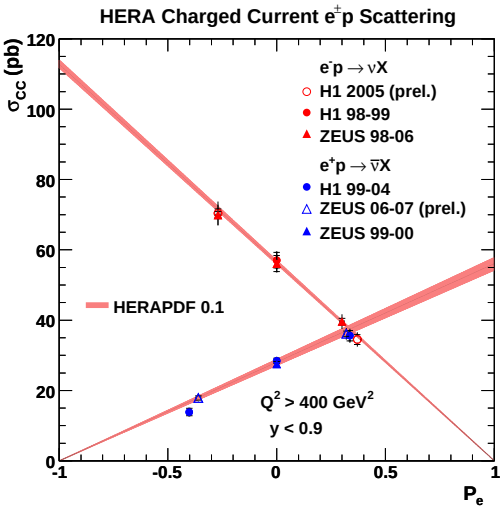

Figure 4: *Total cross sections for e^-p and e^+p CC DIS as a function of longitudinal electron (positron) beam polarization.*

The HERA [8, 9] results are shown in Fig. 5 and compared to LEP and CDF results [10, 11].

6 Isolated Lepton Events with Missing P_T

A search for events with high transverse energy isolated leptons (electrons or muons) and missing transverse momentum has been performed by the H1 and ZEUS collaborations [12] using the full data sets. In general, the observed events yields are in good agreement with the SM model predictions, which is dominated by W production. An excess at high P_T^X, $P_T^X > 25\,\text{GeV}$, is observed by H1 in the e^+p data sample, which is not observed by ZEUS. A small excess remains in the common analysis [12]: the number of observed events with $P_T^X > 25\,\text{GeV}$ is 23, compared to 14.0 ± 1.9 expected.

The measured single W production cross section is shown in Fig. 6. The total cross section of this process is measured as $1.07 \pm 0.16(\text{stat.}) \pm 0.08(\text{sys.})\,\text{pb}$, in agreement with the SM prediction of $1.26 \pm 0.19\,\text{pb}$.

7 Multi-Lepton Production

The production of multileptons (electron or muon) at high transverse momenta has been studied by the H1 and and ZEUS collaborations [13] using the full $e^\pm p$ data sample. The yields of di- and tri-lepton events are in good agreement with

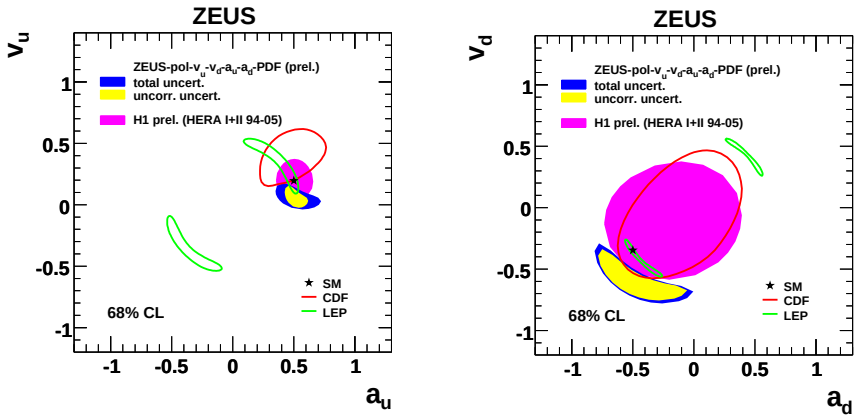

Figure 5: *Contour plots of the 68% C.L. limits on the electroweak couplings of the quarks to the Z^0 boson. Left side v_u vs. a_u (u quarks). Right side v_d vs. a_d (d quarks).*

SM predictions. Distributions of the invariant mass M_{12} of the two highest P_T leptons and of the scalar sum of the lepton transverse momenta $\sum P_T$ are in good agreement with the SM expectations. Events are observed in $ee, e\mu, eee$ and $e\mu\mu$ topologies with invariant masses M_{12} above 100 GeV, where the SM prediction is low. Both experiments observe high mass and high $\sum P_T$ events in e^+p collisions only, while, for comparable SM expectations, none are observed in e^-p collisions. In the combined analysis seven events have a $\sum P_T > 100\,\text{GeV}$, whereas the corresponding SM expectation for e^+p collisions is 1.94 ± 0.17 events [13] .

The total and differential cross sections for electron and muon pair photoproduction are measured in a restricted phase space dominated by photon-photon interactions and are found in good agreement with the SM expectations.

8 Single-top Production

Observables sensitive to flavor-changing neutral current (FCNC) interactions are particularly useful as probes for physics beyond the SM, since SM rates are very small due to the GIM mechanism. At the HERA collider, single-top production is a prime reaction to search for FCNC, where the incoming lepton exchanges a γ or Z with an up-type quark in the proton, producing a top quark in the final state. Deviations from the SM can be parameterized in terms of the coupling constants $\kappa_{tu\gamma}$, v_{tuZ} [14].

The studies performed by H1 and ZEUS considered top quark decays into a b quark and a W boson with subsequent leptonic or hadronic decay of the W.

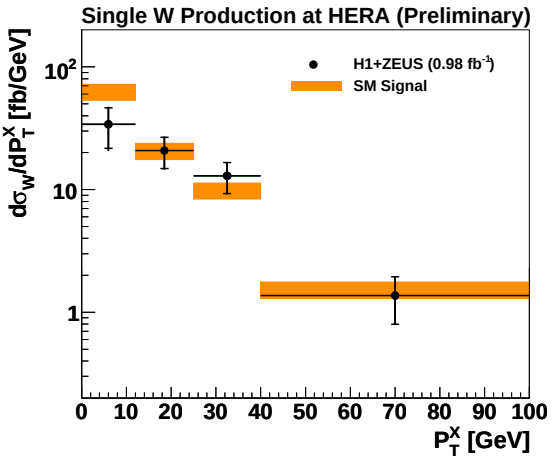

Figure 6: *The differential single W cross section plotted as a function* P_T^X.

The search is therefore based on a sample of events with isolated leptons and missing transverse momentum and a sample of multi-jet events. No evidence for single top quark production is observed. A 95% C.L. limit on the anomalous coupling $\kappa_{tu\gamma}$, $\kappa_{tu\gamma} < 0.18$ for H1 [15] and $\kappa_{tu\gamma} < 0.13$ for ZEUS [16] is set for the scale of new physics of $\Lambda \equiv m_{top} \equiv 175\,\text{GeV}$.

9 Are Quarks elementary?

A possible quark sub-structure can be detected by measuring the spatial distribution of the quark charge. If the quark has a finite radius, the cross section will decrease as the probes penetrates into it. Deviations from the SM cross section are described by:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{\text{SM}}}{dQ^2}\left(1 - \frac{R_q^2}{6}Q^2\right)^2\left(1 - \frac{R_e^2}{6}Q^2\right)^2,$$

where R_e and R_q are the root-mean-square radii of the electroweak charge of the electron and the quark, respectively.

The high Q^2 ($Q^2 > 1\,000\,\text{GeV}^2$) neutral current data sample has been used for this analysis. Assuming the electron to be point-like, the 95% C.L. limit on the quark radius is obtained as: $R_q < 0.74 \cdot 10^{-18}\,\text{m}$ (H1 [2]) and $R_q < 0.63 \cdot 10^{-18}\,\text{m}$ (ZEUS [17]).

The ZEUS data set has also been used to derive limits on the mass scale parameter in models with large extra dimensions and on the effective mass scale limits for contact-interaction model ranging from 3.8 to 8.9 TeV [17].

10 Search for Excited Fermions

Excited fermions ($e^\star, \nu^\star$and $q^\star$) would be a signature of compositeness at the compositeness scale Λ. The cross section is proportional to the coupling constants f and $f^{'}$ [18]. All electroweak decays of excited fermions have been considered, including final states from Z or W hadronic decays. No evidence for excited fermion production is found. Exclusion limits on f/Λ at 95% C.L. are determined by H1 as a function of the mass of the excited fermions. Assuming $f/\Lambda = 1/M_{f^\star}$, the following mass limits are derived at 95% C.L.: $M_{e^\star} > 272\,\text{GeV}$, $M_{\nu^\star} > 213\,\text{GeV}$ and $M_{q^\star} > 252\,\text{GeV}$ (for $f_s = 0$) [18,19].

11 Leptoquarks

A search for scalar and vector leptoquarks (LQ) coupling to first generation fermions has been performed by the H1 collaboration using the full HERA data set [20]. Leptoquark decays into eq and νq were considered, where q represents both quarks and anti-quarks. Such LQ decays lead to final states similar to those of DIS NC and CC interactions at very high Q^2. No evidence for direct or indirect production of leptoquarks is found in data samples with a large transverse momentum final state electron or with large missing transverse momentum. For each of the LQ species defined in the Buchmüller-Rückl-Wyler (BRW) model [21], the present analysis excludes a previously unexplored domain in the plane spanned by the mass of the leptoquark and its coupling to fermions.

As an example limits on the coupling λ for $\tilde{S}_{1/2,L}$ and $S_{0,L}$ leptoquarks are shown in Fig. 7 as function of the LQ mass.

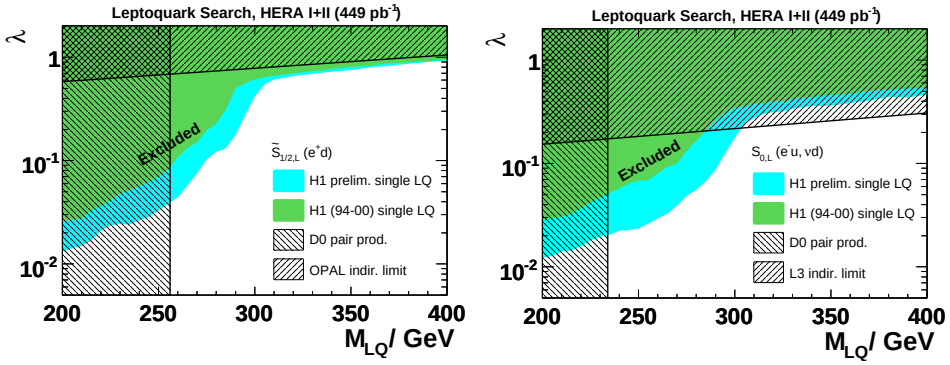

Figure 7: *Limits of the coupling constant λ for $\tilde{S}_{1/2,L}$ and $S_{0,L}$ leptoquarks as a function of their mass.*

12 General Searches for High - P_T Phenomena

H1 performed a model independent, generic search in final states with at least two high-P_T objects: electrons, muons, jets, photons or neutrinos [22]. The transverse momentum of these objects is required to be larger than 20 GeV. The events were classified according to their final states. Forty different final states were considered. In general, the events yields are in good agreement with Standard Model expectations. No statistically significant deviation is observed.

Acknowledgments

I would like to thank the organizers, in particular A.Studenikin, for the invitation to the conference. I am grateful to M.Turcato and S.Schmitt for a critical reading of the manuscript.

References

[1] A.M. Cooper-Sarkar, R.C.E. Devenish and A. De Roeck, *Int. J. Mod. Phys.* **A 13**, 3385 (1998).
[2] H1 Collaboration, prelim-07-141.
[3] H1 Collaboration, prelim-06-041.
[4] ZEUS Collaboration, ZEUS-prel-09-001.
[5] A. Aktas et al., H1 Collaboration, *Phys. Lett.* **B634**, 173 (2006).
[6] S.Chekanov et al., ZEUS Collaboration, *Eur. Phys. J.* **C 62**, 625 (2009).
[7] H1 and ZEUS Collaborations, H1 prelim-06-142 and ZEUS prel-06-022.
[8] A. Aktas et al., H1 Collaboration, *Phys. Lett.* **B632**, 35 (2006).
[9] S.Chekanov et al., ZEUS Collaboration, ZEUS-prel-07-027.
[10] D. Acosta et al., CDF Collaboration, *Phys. Lett.* **B634**, 173 (2006).
[11] LEP Electroweak Working Group, *Phys. Rep.* **427**, 257 (2006).
[12] H1 and ZEUS Collaborations, H1 prelim-09-161, ZEUS-prel-09-044.
[13] H1 and ZEUS Collaborations, *JHEP10* 013 (2009).
[14] T. Han, J.L. Hewett, *Phys. Rev.* **D60**,074015 (1999).
[15] F.D.Aaron et al., H1 Collaboration, DESY 09-050 (2009).
[16] ZEUS Collaboration, ZEUS-prel-09-009.
[17] ZEUS Collaboration, ZEUS-prel-09-013.
[18] F.D.Aaron et al., H1 Collaboration, *Phys. Lett.* **B678**, 335 (2009).
[19] F.D.Aaron et al., H1 Collaboration, DESY 09-040, arXiv:0904.3392v2 (2009).
[20] H1 Collaboration, H1 prelim-07-164, (2007)
[21] W.Buchmüller, R.Rückl and D.Wyler, Phys.Lett. **B191**, 442 (1987). Erratum in Phys.Lett. **B448**, 320 (1999).
[22] F.D.Aaron et al., H1 Collaboration, *Phys. Lett.* **B 674**, 257 (2009).